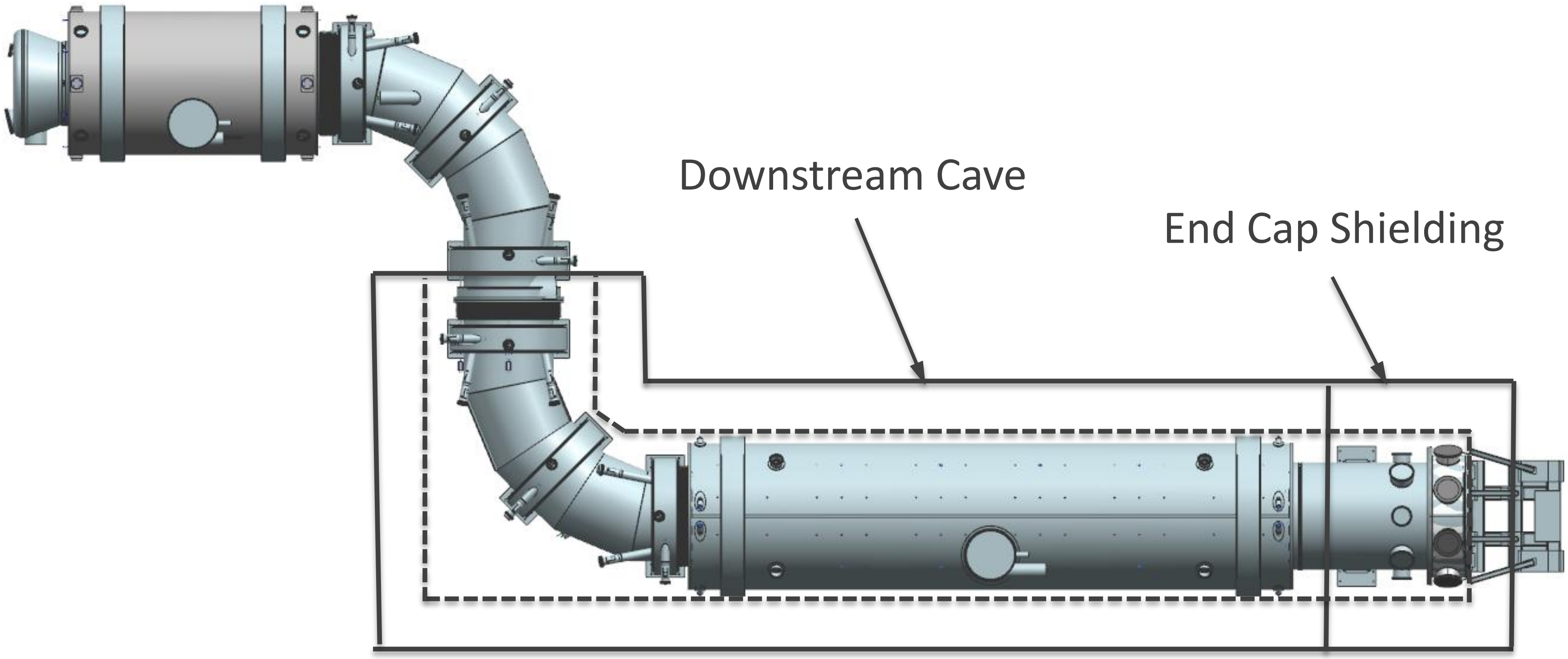
# WBS 5.9 Downstream External Shielding
# Mu2e CD-2 Review

Rodger Bossert
Muon Beamline Level 3 Manager: Mu2e Downstream External Shielding
10/21/2014

# Overview of the Orientation:



# Requirements

Shielding needs to be placed around the downstream Transport Solenoid (TSd) and the Detector Solenoid (DS) to limit the number of neutrons and gammas reaching the Cosmic Ray Veto Counter.  This shielding will be supported on the lower level floor of the Mu2e Experiment Hall.

The Mu2e Downstream External Shielding requirements and specifications are documented in Mu2e-doc-1371.

The downstream external shielding is designed to facilitate detection of the experimental signature events by reducing the experimental background rates. Physics requirements are:

- Reduce the neutron and gamma background incident upon the Cosmic Ray Veto (CRV) Counters to achieve acceptable detector livetime (≥ 90%) and to protect the CRV from radiation damage.
- Allow a line of sight to the Muon Stopping Target Monitor (STM) and reduce the neutron and gamma background incident upon the STM.

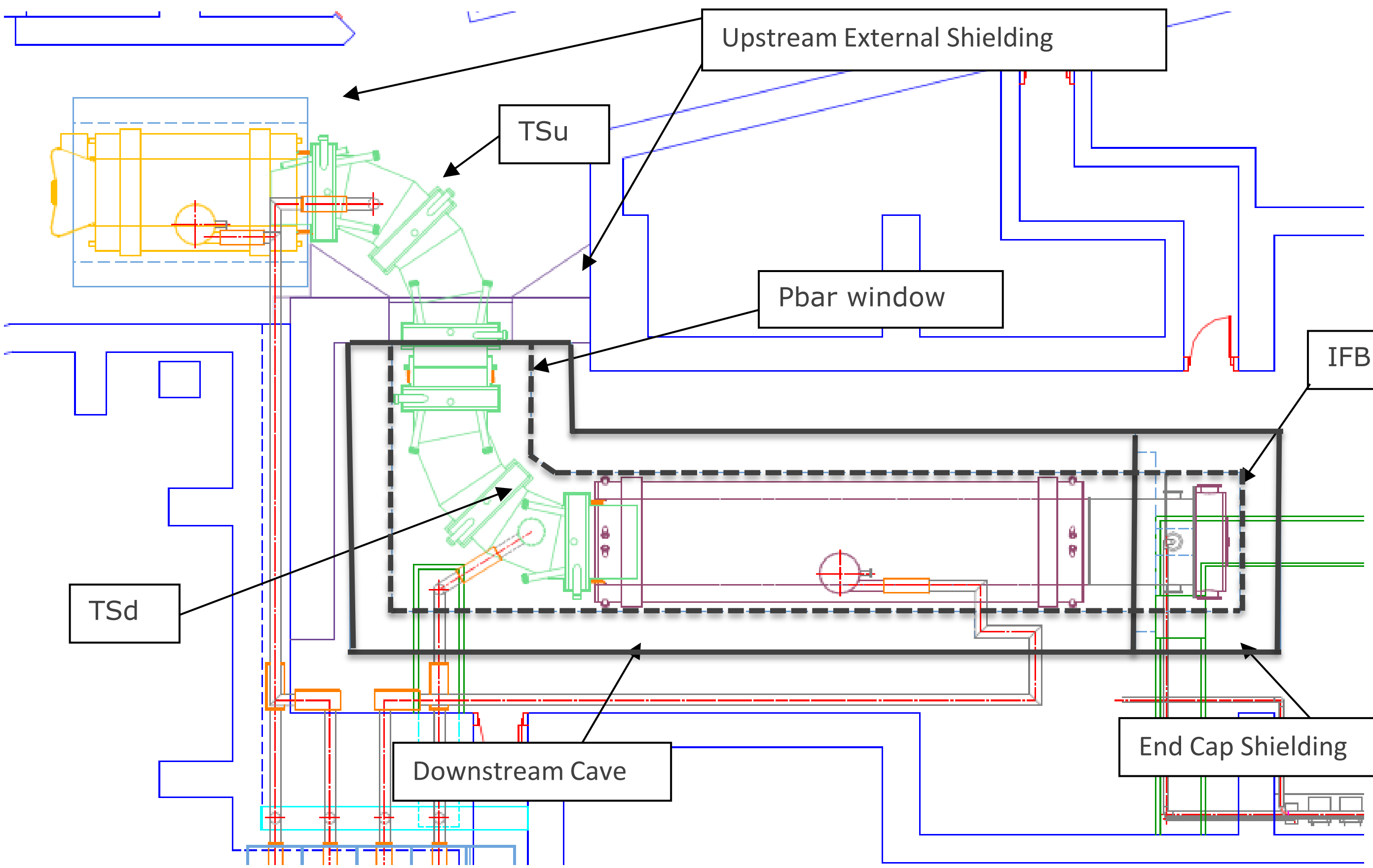
# Requirements

In addition to the above physics requirements, the downstream external shielding must satisfy the following mechanical requirements:

- Provide a base for support of the CRV modules (as well as facilitate temporary storage of additional CRV modules removed from the upstream end during access to the pbar window at the TSu/TSd interface).
- Facilitate access to the Instrumentation Feedthrough Bulkhead (IFB) and the detector train inside the DS.
- Facilitate access to the pbar window and the collimator rotation mechanism located at the TSu/TSd interface.
- Accommodate passage of power, cryo and vacuum services to the DS while reducing rates of particles escaping through this penetration.
- Reduce rates of particles escaping through the TSd trench as appropriate.
- Reduce rates of particles escaping through the DS trenches as appropriate.
- Stay clear of the solenoids during installation, and satisfy the constraints imposed by the building geometry.
- Provide a relatively economical structure that is mechanically stable and servicable while allowing for adequate exit pathways.

# Design

The Downstream External Shielding consist of two parts, the Downstream Cave and the independent End Cap Shielding. The Downstream Cave is placed around the TSd and DS, and the End Cap Shielding surrounds the downstream end of the muon beamline vacuum enclosure. All Downstream External Shielding is supported independently of the DS.

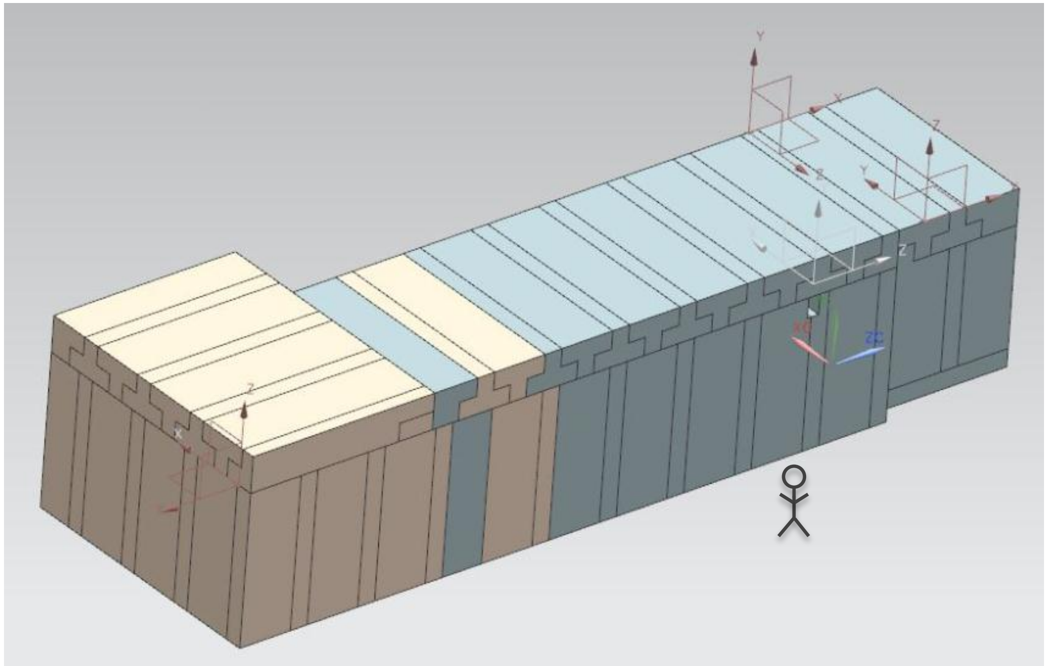


# Design

The current design of the shielding requires 36 inch thick concrete to sufficiently suppress the rates at the CRV. The upstream (or TSd) end of the downstream cave, which surrounds the TSd is composed of high density (barite) concrete. The concrete blocks surrounding the muon stopping target region of the DS are also anticipated to be composed of high density (barite) concrete, while the remainder of the concrete blocks are normal density concrete.

The downstream cave is composed of 409 tons of high density concrete and 312 tons of normal density concrete. The end cap shielding is composed of 117 tons of normal density concrete.

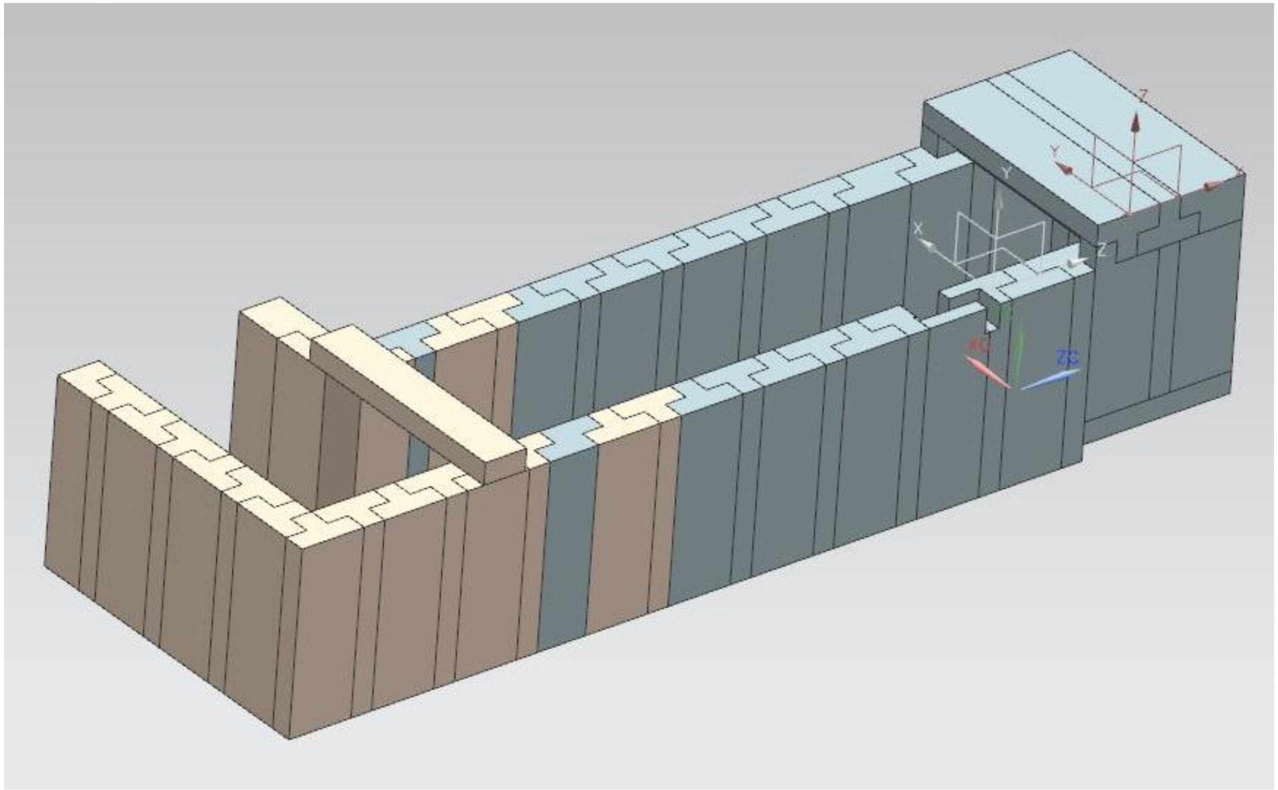
The Downstream Cave (shown to the right) consists primarily of "T" shaped blocks. Concrete blocks are gray while Barite blocks are brown.



# Design

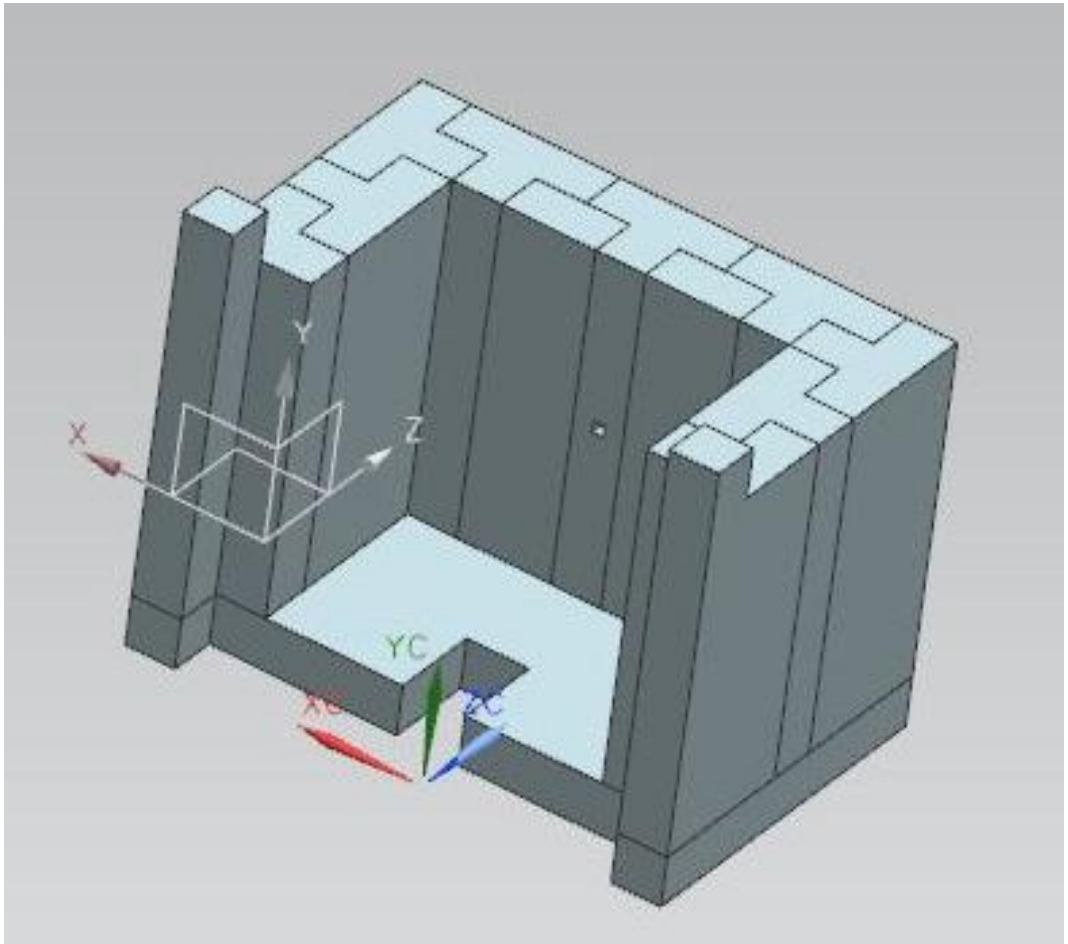
The Downstream Cave is shown below with the roof blocks removed.

The configuration of the “T” blocks which comprise the wall is clear in this view.



# Design

End cap shielding block assembly as seen from the upstream end (looking towards the north east) prior to installation of the top blocks. The roof is not shown.




The End Cap Shielding will be supported underneath by Hilman rollers (not shown). The assembly will be moved away from the Downstream Cave and rolled downstream for access to the components when they are removed for maintenance (see WBS 5.10).

The slot shown at the bottom is needed to accommodate services from the Detectors.

# Design

## Tolerances and related constraints

The Downstream External Shielding is restricted on both the inside and outside surfaces (by the Detector Solenoid and CRV panels respectively), so block placement tolerances are important.

The location of the downstream cave is constrained on the upstream end by the upstream external shielding and on the north, west and south sides by the solenoids and on east side by the north south DS trench. Since the intent is to minimize line of sight cracks, the tolerances on the blocks and the spacing between blocks must accommodate these various constraints.

The Downstream Cave will include a side penetration to accommodate services for the Detector Solenoid, and the End Cap Shielding will include a penetration at bottom to accommodate services for the Tracker and Calorimeter.

Standard concrete block tolerances should accommodate the above cited assembly constraints.

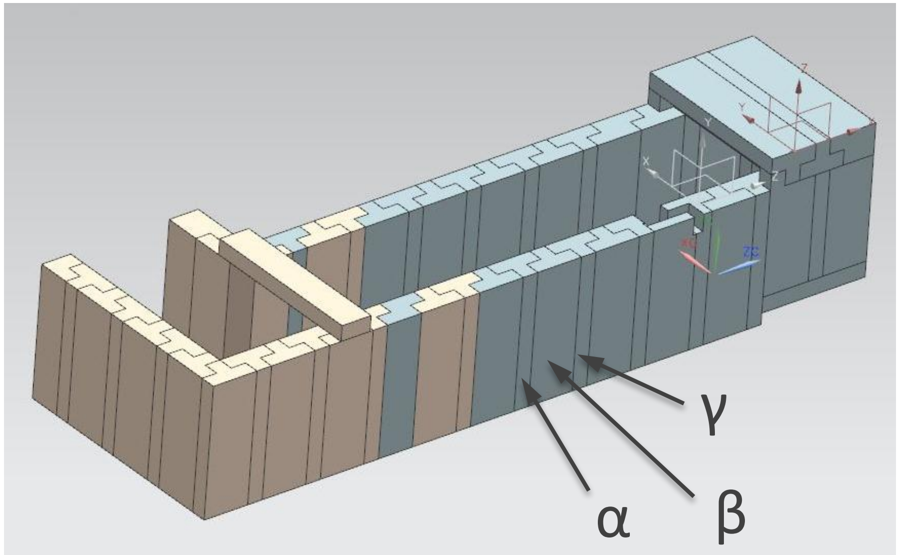
# Installation

- The concrete blocks which constitute the downstream cave will be assembled around the TSd and DS cryostats after installation and commissioning of the solenoids is complete, using the available overhead building cranes.
- The part of the downstream cave surrounding the DS is not currently expected to be removed during the life of the project, but should be designed so that it can be removed if necessary.
- The part of the downstream cave surrounding the TSd may need to be moved to provide access to the antiproton stopping window assembly at the TSu/TSd interface or the COL3u and COL3d collimator rotation mechanism.
- The End Cap Shielding is designed to allow the assembly to be rolled backward behind the external stands when the components internal to the DS are removed for maintenance.

# Installation Sequence

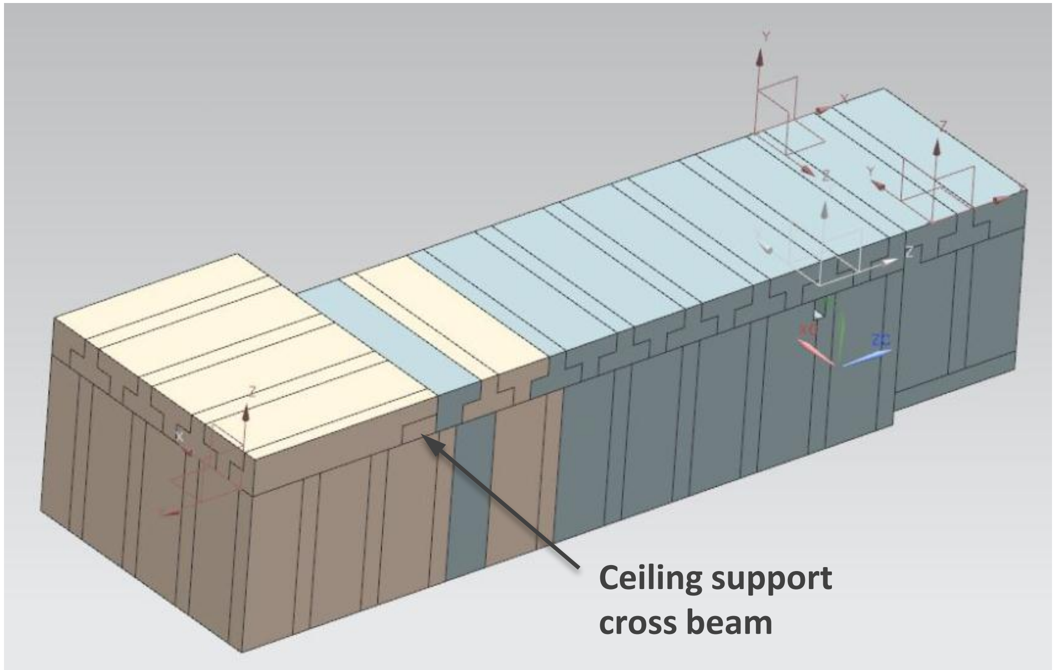
A brief summary of the installation process follows:

1. Install the floor level block alignment feature (standoffs).
2. Begin the sequence of installation of side wall blocks starting from the upstream end and moving towards the downstream end in repeated steps as follows:
   a. Install T block (call this block α for the moment) with long side nearest solenoid
   b. Temporarily position appropriate spacer next to this block
   c. Install next T block (call this block γ) with long side nearest solenoid
   d. Extract temporary spacer from between the two blocks α and γ just installed
   e. Install T block (call this block β) with long side away from solenoid between T blocks α and γ
   f. And repeat this sequence until the side walls are complete



# Installation Sequence

Once the side walls of the downstream cave are installed, the ceiling blocks can be installed, starting with the TSd ceiling support cross beam near the upstream end of the DS. Pairs of T blocks with the long sides down must be installed before the mating block can be installed in between the pair.




Due to the hatch beam which supports the TS hatch blocks direct crane access to the region near the upstream end of the DS is occluded.

As a result, blocks under the hatch beam may me installed using a coordinated lift with both building cranes, and a spreader.

Alternatively, the blocks that are not under crane coverage could be installed via counterbalanced lifts.

# Improvements since CD-1

- Increased shielding around DS from 18 inches thick to 36 inches thick as a result of an improved understanding of radiation effects
- Include high density concrete around stopping target
- Extend cave to surround TSd (entirely high density concrete)
- Minimize cracks in downstream cave (introduced T-block design)
- Added penetration for DS services
- Exploring the impact of trenches on CRV performance
- Planned installation sequence

# Value Engineering since CD-1

– Increase concrete thickness instead of higher density concrete in many places

- Simulations verify that stainless steel reinforcement bar is not necessary.

– Eliminate stainless steel frame from DS cave

– Plan for multiple use of same hydraulic system with Upstream External Shielding and solenoid installation

# Downselects

Explored several different shielding configurations and arrived at one that addresses detector performance requirements (adjusted amount, size and position of barite blocks).

# Performance

– Extensive simulations have been completed since CD1 to understand the necessary requirements for the Downstream External Shielding

– The Downstream External Shielding has been redesigned to achieve the performance goals dictated by the simulations

– See the CRV presentation in particular for a summary of the current performance of the external shielding

# Remaining work before Fabrication

- Continue simulations to further optimize configuration
- Complete testing of Barite composition for thermal and structural viability.
- Optimize design of shielding for penetrations
- Finalize structural components to install blocks into place
- Refine and finalize the installation procedures/sequence.

# Quality Assurance

- Quality Assurance in the Downstream External Shielding efforts rely on the following tools :
  - Fermilab Quality Assurance Manual
  - Fermilab Engineering Manual
  - Documented engineering calculations and drawings
    - reviewed, approved and released
  - Verification of physics simulations
    - Comparisons between MARS and GEANT4
  - Prototypes and mockups as appropriate
  - Documentation of procedures
  - Delivered materials will be inspected for conformance to the specifications

# Risks

– Damage to surrounding elements during shielding installation

  • Mitigated via standoffs (to avoid damage) and simplified installation.

– Shielding installation impacts beamline alignment.

  • Mitigated by civil construction plans

– Background rates in Cosmic Ray Veto higher than anticipated.

  • Simulation studies are ongoing to minimize this risk (but the residual risk will by necessity be transferred since this risk would only be realized after the project horizon.

# Integration and Interfaces

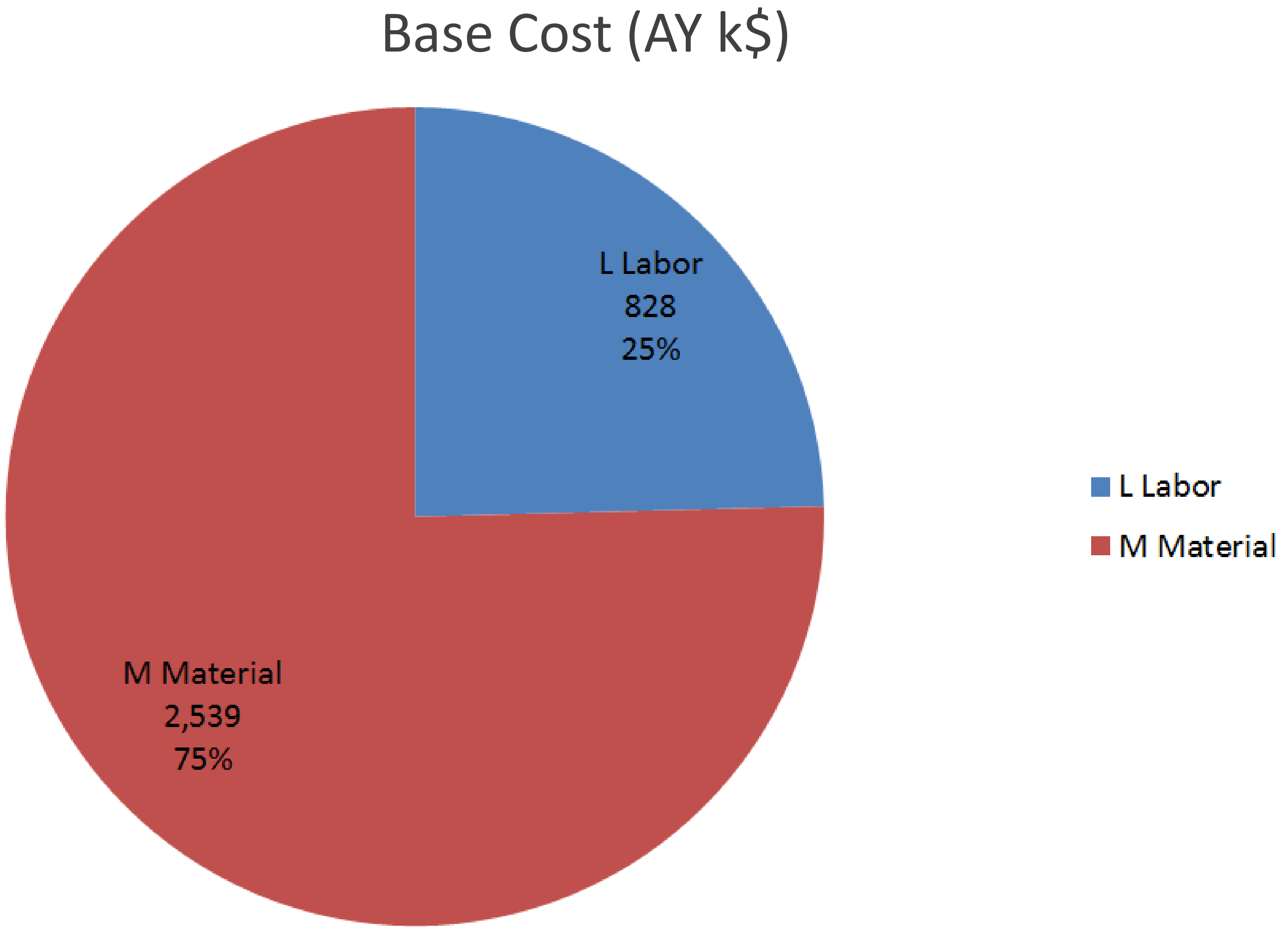
- The Downstream External Shielding has external interfaces to the Cosmic Ray Veto, the Detector Solenoid, the Transport Solenoid, and Conventional Construction.
- Internal interfaces with the Vacuum System, Upstream External Shielding, Detector Support Structure, Stopping Target Monitor and Muon Beam Stop.
- In particular, important interfaces involve
  - support for the CRV modules by the concrete block assemblies
  - sensitivity of the concrete block assembly to variations in floor elevation.
  - penetration of the concrete blocks for services to the solenoids
  - provision of space for access to the detector train and DS bore
  - provision of space for services to the tracker and calorimeter
  - Line of sight through the End Cap Shielding to the Stopping Target Monitor
- Formal sign-off between owners of all external interfaces as part of final design requirements.
- Muon Beamline personnel participate in bi-weekly integration meetings

# ES&H

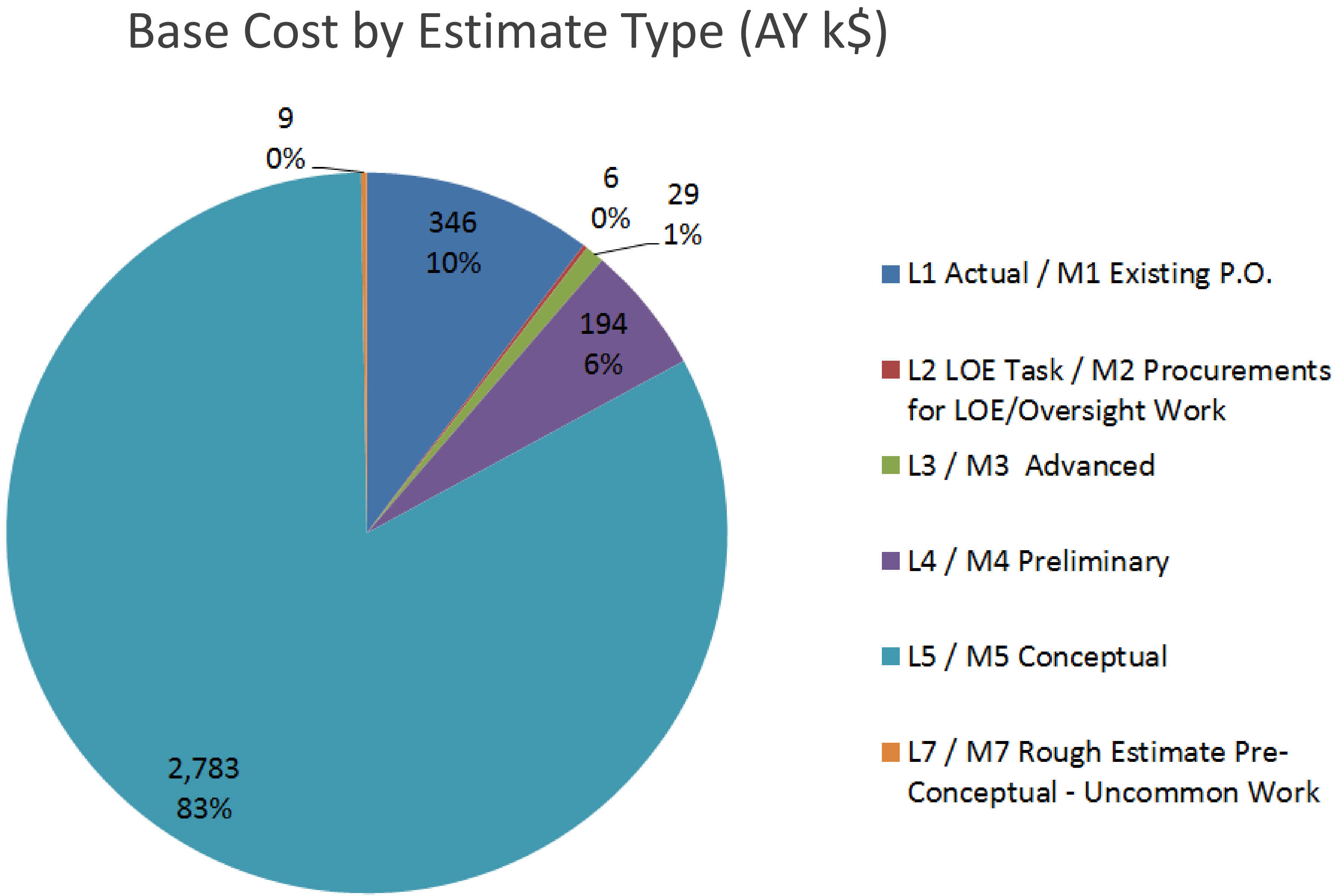
To perform Downstream External Shielding activities safely will require appropriate planning (JHA), attention to ES&H considerations and FESHM and FRCM requirements

- Accessing confined space FESHM 5063
- Crane, hoist, and forklift use FESHM 5021
  - Including lifts beyond direct crane coverage
- Fall Hazards FESHM 5066
- Magnetic fields FESHM 5062.2
- Electrical hazards FESHM 5042
- Hydraulic and perhaps pneumatic systems (and potential stored energy)
- Radiation hazards FRCM
  - Activation by beam
- And possibly ODH
  - FESHM 5064

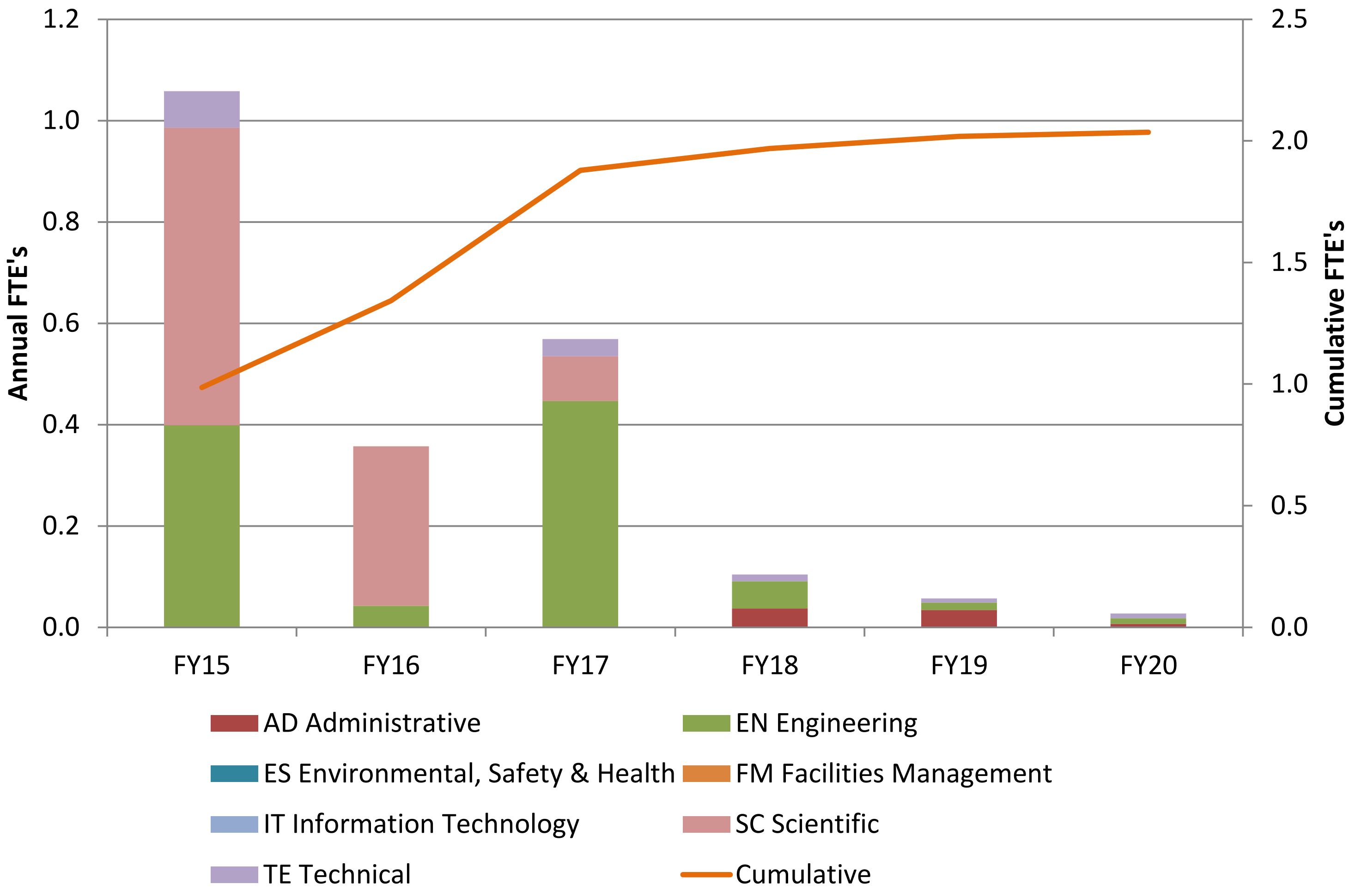
# Cost Distribution by Resource Type



# Quality of Estimate



# Labor Resources by FY



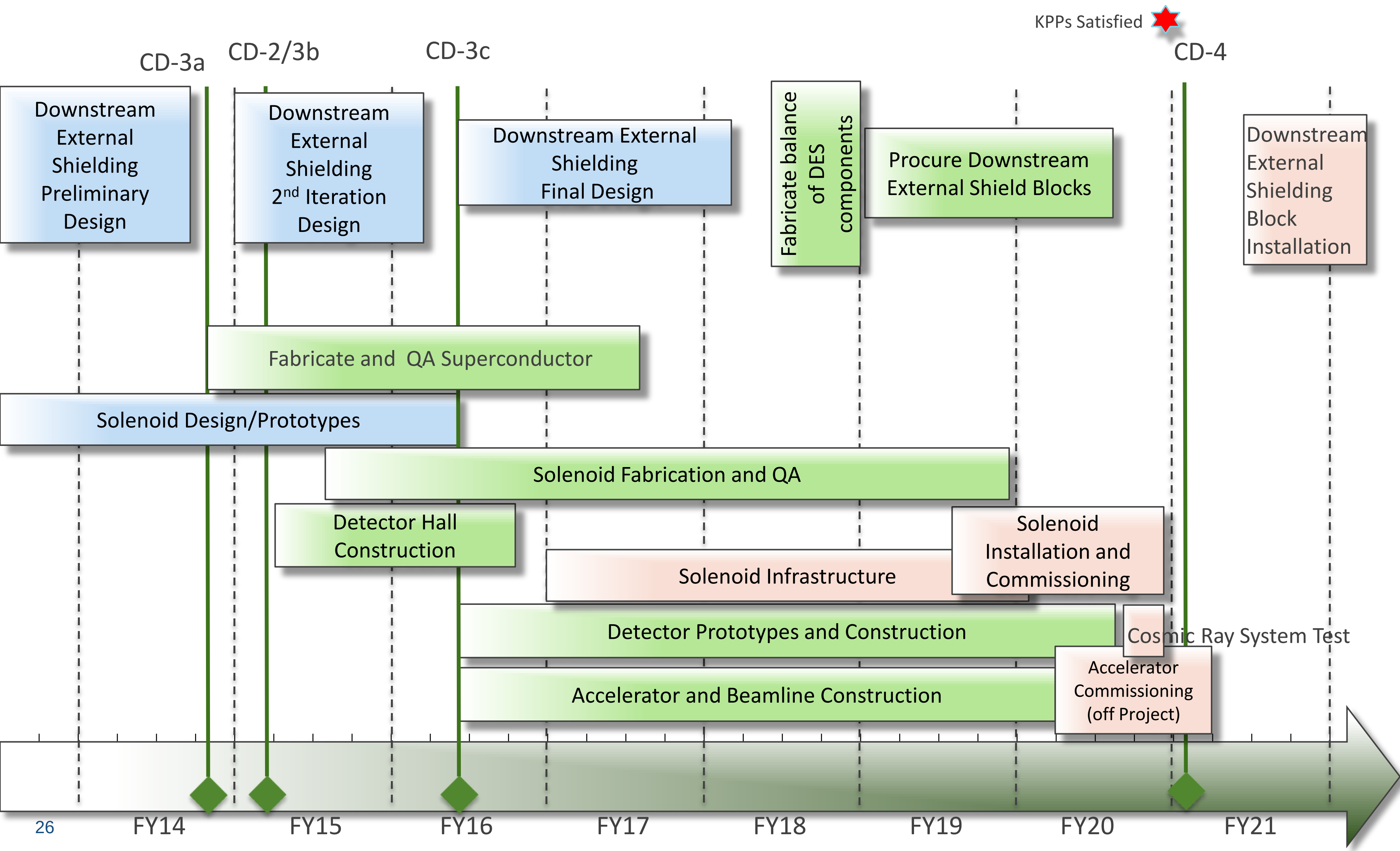
# Cost Table

WBS 5.9 Downstream External Shielding

Costs are fully burdened in AY k$

| | Base Cost (AY K$) | | | | | |
|---|---|---|---|---|---|---|
| | M&S | Labor | Total | Estimate Uncertainty (on remaining budget) | % Contingency (on remaining budget) | Total Cost |
| 475.05 Muon Beamline | | | | | | |
| 475.05.09 Downstream External Shielding | | | | | | |
| 475.05.09 Downstream External Shielding | 2,539 | 828 | 3,367 | 1,368 | 45% | 4,735 |
| Grand Total | 2,539 | 828 | 3,367 | 1,368 | 45% | 4,735 |

# Schedule



KPPs Satisfied
CD-3a
CD-2/3b
CD-3c
CD-4
Downstream External Shielding Preliminary Design
Downstream External Shielding 2nd Iteration Design
Downstream External Shielding Final Design
Fabricate balance of DES components
Procure Downstream External Shield Blocks
Downstream External Shielding Block Installation
Fabricate and QA Superconductor
Solenoid Design/Prototypes
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Installation and Commissioning
Solenoid Infrastructure
Detector Prototypes and Construction
Cosmic Ray System Test
Accelerator Commissioning (off Project)
Accelerator and Beamline Construction
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

# Major Milestones

| Activity ID | Milestone Name | Milestone Date |
|---|---|---|
| 47505.9.001725 | Downstream External Shielding 2nd iteration design complete | November 10, 2015 |
| 47505.9.001915 | Downstream External Shielding ready for CD 3c Review | December 14, 2015 |
| 47505.9.001916 | CD 3 Approval Downstream External Shielding. | February 23, 2016 |
| 47505.9.010001 | Advanced Procurement Plan for DES Concrete Fabrication Complete | November 21, 2017 |
| 47505.9.010005 | Vendor for DES Concrete Fabrication Selected | December 19, 2018 |
| 47505.9.061010 | All DES components at FNAL | May 01, 2020 |
| 47505.9.061020 | Downstream External Shielding ready for CD-4 | May 29, 2020 |

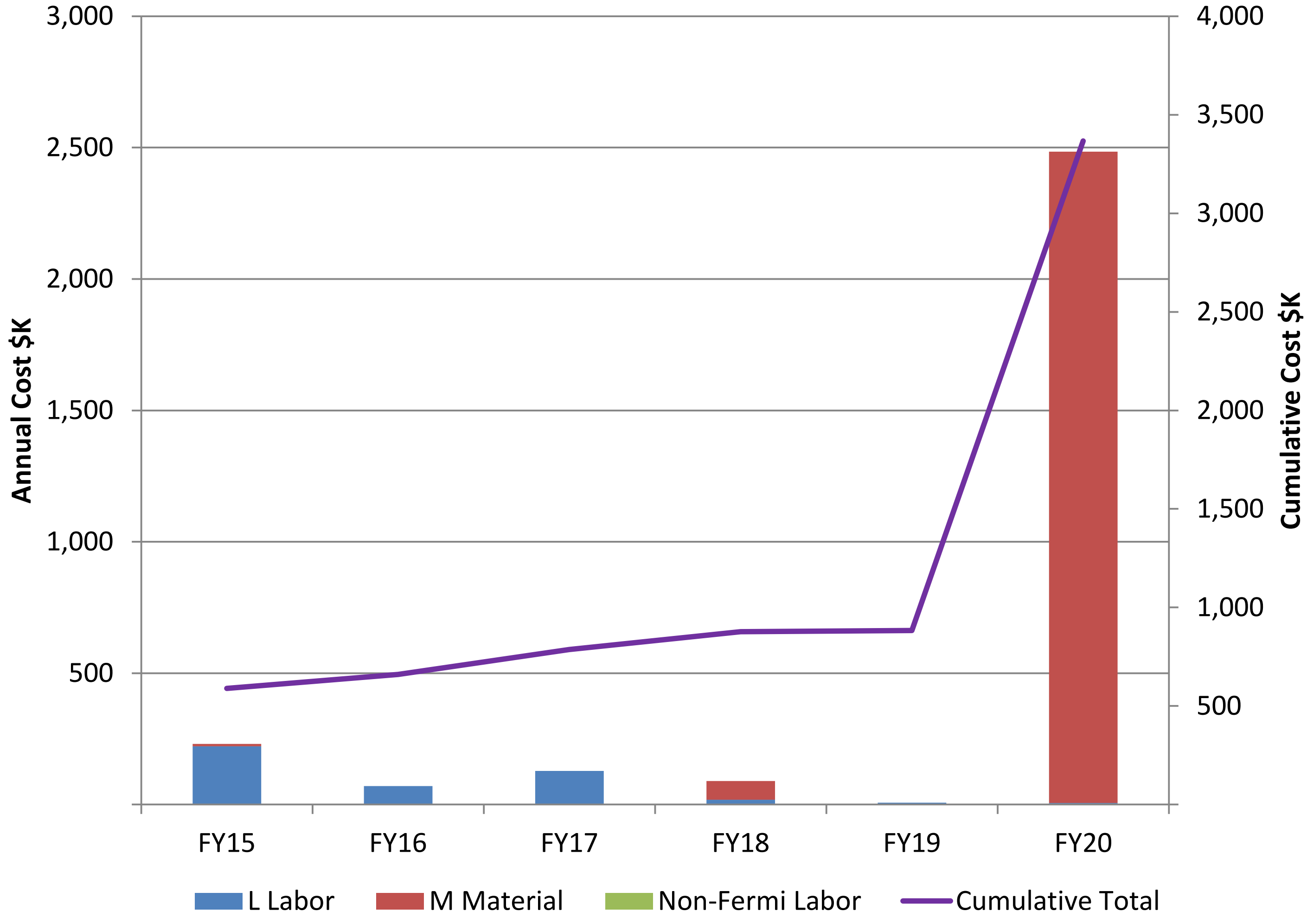
# Summary

- Have made substantial progress since CD-1
  - Designs have been significantly refined/optimized
    - Shielding wall thickness
    - Block shapes and materials changed
    - Installation procedure refined
  - Simulations show that the preliminary design meets the requirements

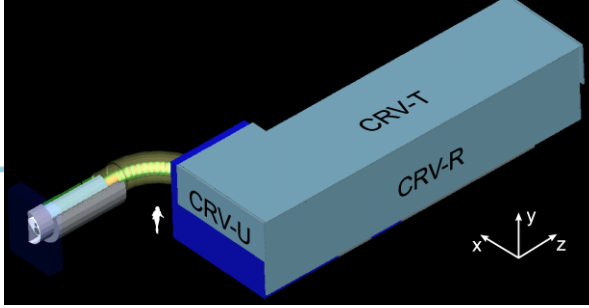
- Risks are understood and mitigated to the extent possible.
- Interfaces are identified and resource needs are understood.
- The Downstream External Shielding is ready for CD-2

# Backup Slides

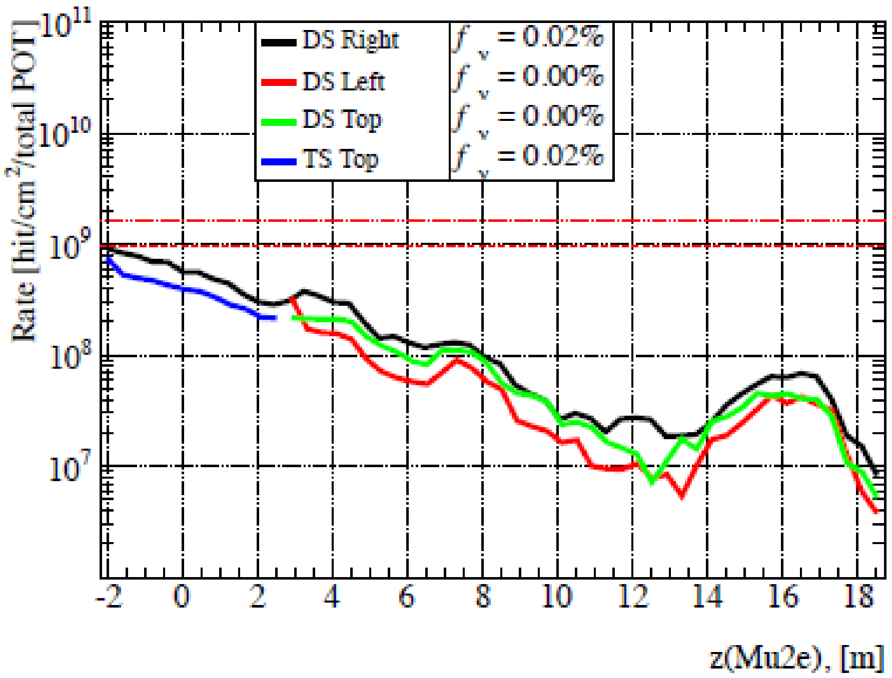
# Labor/Material Breakdown (AY k$)

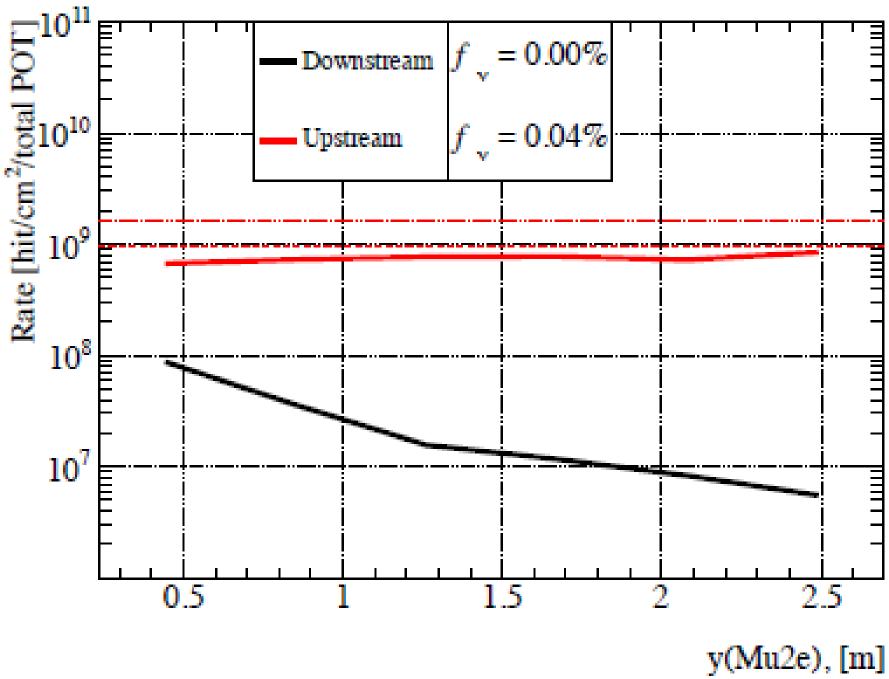


# Accidental CRV rates

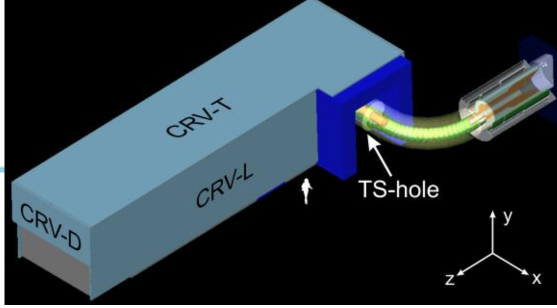



- Accidental hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.
- CRV deadtime requirement is ≤ 10%

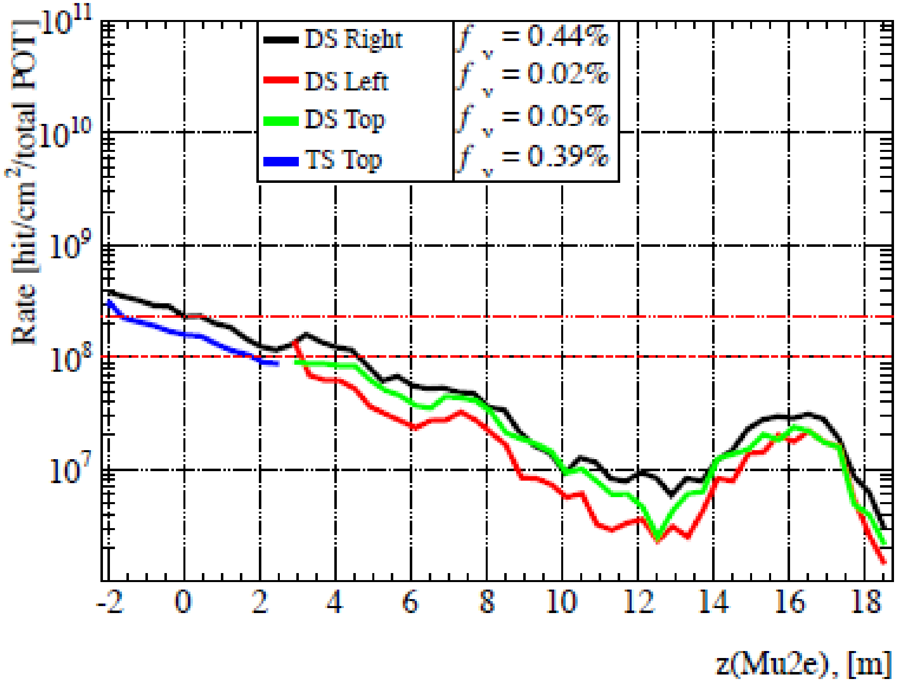


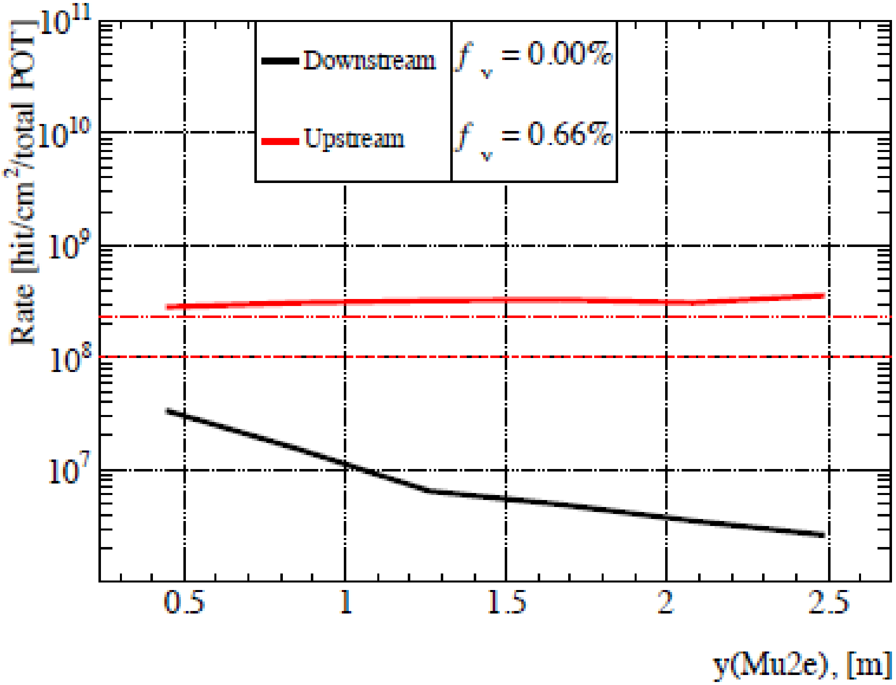



# Semi-correlated CRV rates

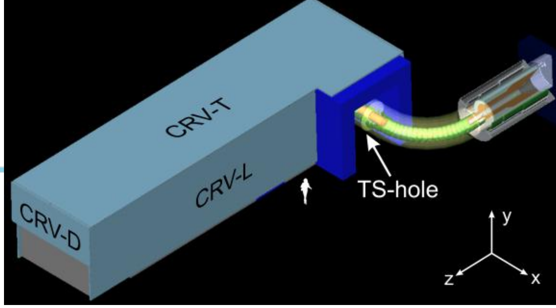



- Semi-correlated hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.
- CRV deadtime requirement is ≤ 10%

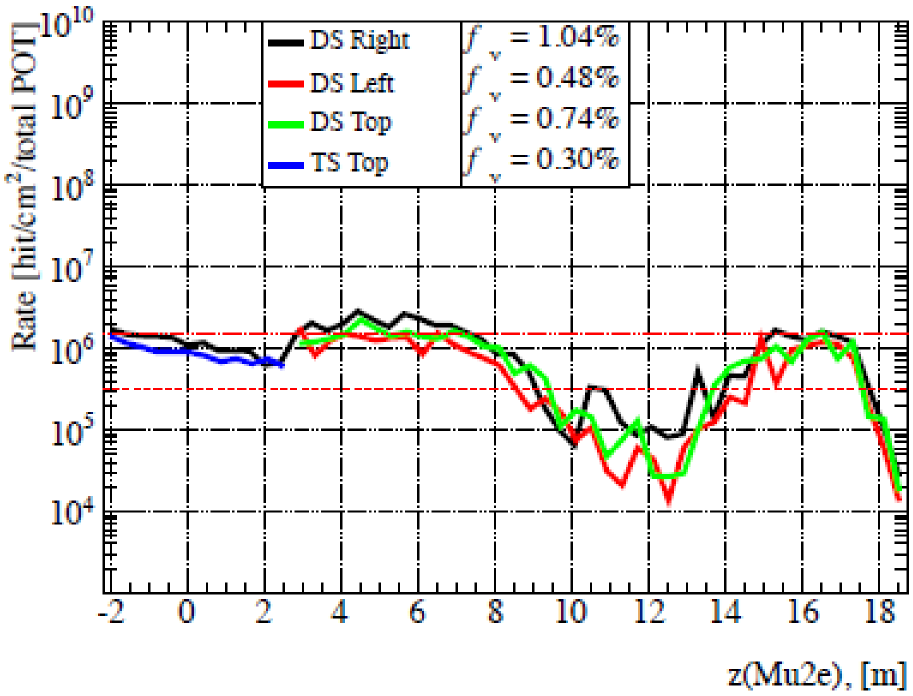


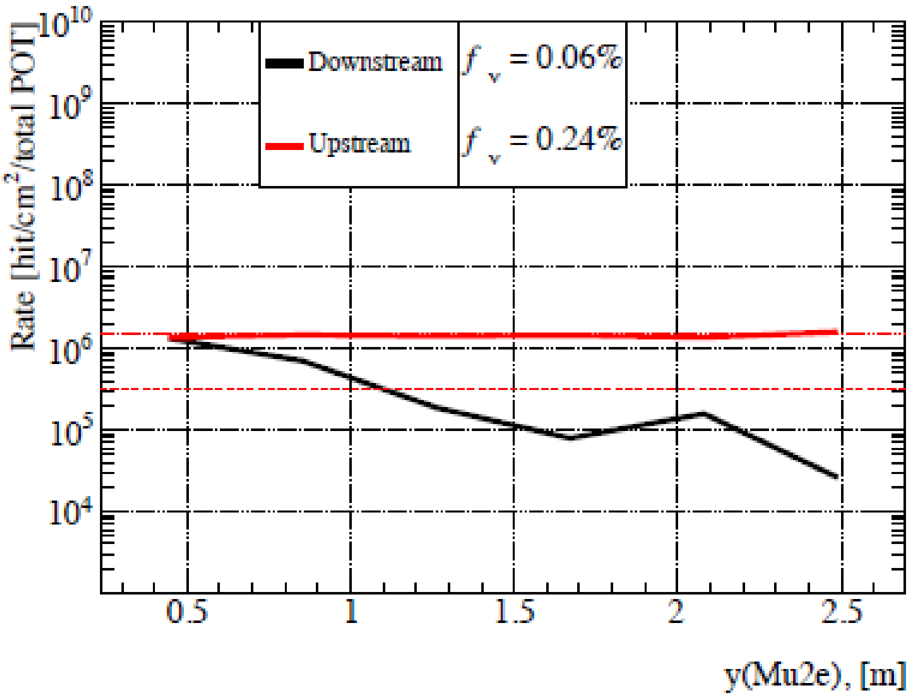



# Correlated CRV rates




- Correlated hit rates per unit area over the entire running period. Dashed and dotted red lines correspond to 1% and 5% fractional dead time assuming uniform flux distribution.
- CRV deadtime requirement is ≤ 10%



# General Features of Blocks needed for DES

| Downstream External Shielding | | | | | | |
|---|---|---|---|---|---|---|
| | | | PER BLOCK | PER BLOCK | PER BLOCK | |
| BLOCK LABEL | SHAPE | MATERIAL | VOLUME | WEIGHT | | # OF BLOCKS |
| | | | (CU. FT.) | (LBS) | (LBS) | |
| | | | | BARITE | CONCRETE | |
| BT-152 | T | BARITE | 114.0 | 25080 | | 17 |
| BLU-152 | L | BARITE | 92.3 | 20306 | | 1 |
| BLD-152 | L | BARITE | 162.0 | 35640 | | 1 |
| BRH-194 | R | BARITE | 72.8 | 16005 | | 1 |
| BOT-152 | Odd | BARITE | 131.4 | 28908 | | 1 |
| CZR-152 | Z | CONCRETE | 133.0 | | 19285 | 1 |
| CT-152 | T | CONCRETE | 114.0 | | 16530 | 17 |
| CT1-152 | T | CONCRETE | 111.0 | | 16095 | 1 |
| CT2-152 | T | CONCRETE | 107.0 | | 15515 | 1 |
| CT3-152 | T | CONCRETE | 106.9 | | 15501 | 1 |
| CZL-152 | Z | CONCRETE | 171.0 | | 24795 | 1 |
| CTR-157 | T | CONCRETE | 102.5 | | 14863 | 1 |
| CTL-157 | T | CONCRETE | 102.5 | | 14863 | 1 |
| CT-121 | T | CONCRETE | 90.8 | | 13159 | 6 |
| CP1-194 | P | CONCRETE | 214.4 | | 31088 | 1 |
| BLT-194 | L | BARITE | 134.0 | 29480 | | 1 |
| BT-194 | T | BARITE | 145.5 | 32010 | | 3 |
| BT1-194 | T | BARITE | 138.8 | 30525 | | 3 |
| BT2-194 | T | BARITE | 125.3 | 27555 | | 2 |
| BL1-194 | L | BARITE | 81.0 | 17811 | | 1 |
| CLU-194 | L | CONCRETE | 149.5 | | 21678 | 1 |
| CT-194 | T | CONCRETE | 145.5 | | 21098 | 12 |
| CTU-194 | T | CONCRETE | 138.8 | | 20119 | 1 |
| CLD-194 | L | CONCRETE | 190.0 | | 27550 | 1 |
| CTD-121 | T | CONCRETE | 85.4 | | 12383 | 1 |
| CRE-121 | R | CONCRETE | 42.9 | | 6221 | 2 |
| **Total** | | | | | | **80** |

Key to labeling system:

- First symbol designates material, Barite or Concrete
- Second symbol designates cross section shape
- Third symbol (when present) represents a form modifier (number indicates a local relief, and letter indicates a different dimension or cross section shape)
- Numbers after dash indicate nominal block length in inches.

# Properties of barite concrete mix

**Mix #3: Mix Proportions, Fresh Properties of Fermi-Lab Heavyweight Concrete Mix**

| Parameter, units per cubic yard | Fermi-Lab |
|---|---|
| CTLGroup Lab Cement (Lot. 18L0091), lbs | 564 |
| Rad Ban Coarse Aggregate SSD, lbs | 2840 |
| Rad Ban Fine Aggregate SSD, lbs | 2327 |
| Water, lbs | 300.0 |
| Water, gallons | 36 |
| Glenium 3030, BASF fl oz/cwt | 5.0 |
| w/c ratio | 0.53 |
| **Fresh Concrete Properties** | |
| Slump, in. | 4.00 |
| Density, pcf | 219.5 |
| Air Content, % | 2.1 |
| **Average Compressive Strength (psi) *** | |
| 7 days | 5390 |
| 14 days | 5540 |
| 28 days | 5990 |
| **Average Flexural Strength (psi)** | |
| 7 days * | 620 |
| 14 days ** | 640 |
| 28 days ** | 740 |
| **Average Direct Shear (psi)** | |
| 28 days * | 790 |

* Average of three samples.
** Average of two samples.

CTLGROUP Building Knowledge. Delivering Results.

# Backup Slide